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Design, Simulation and Testing of a Precision Alignment Frame for the Next Linear Collider

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DESIGN, SIMULATION AND TESTING OF A PRECISION ALIGNMENT FRAME FOR THE NEXT LINEAR COLLIDER

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Abstract

An alignment frame is developed to support 3 Beam Position Monitors (BPM's) for detecting and ultimately aligning the electron beam from a linear accelerator. This report discusses the design details, preliminary modal analysis of the alignment frame as well as the addition of a metrology frame in the final phase of development.

Introduction

The next generation of linear accelerators will achieve a high rate of interactions by squeezing the electron beams down to spot sizes of 3 nanometers (nm) by 100nm. Studies are underway as part of the Next Linear Collider to collide two of these electron beams head-on. This is possible because of the beam-to-beam interaction caused by the electrical field of one electron bunch deflecting the path of the opposing electron bunch. This deflection can be measured and used as a feedback signal to correct the position of subsequent bunches and bring them into collision (1). The beam's position can be detected through the use of a cavity Beam Position Monitor (BPM). In principle BPM's with nanometer resolution could be constructed and if supported in an alignment frame, they could be used to aim each beam precisely so that a collision would occur.

The BPM assemblies and the alignment tube frame that supports them are shown below in Figure 1. Using the BPM's to measure an electron beam requires that the relative motion among the three BPM's be small during any measurement, thus the need for a stiff support of the BPMS. In addition the BPM's must be able to move relative to each other so they can be used to detect the beam and measure its resolution. This is done initially by moving the tube frame into the region of the beam through the use of 4 linear actuators that support the tube as shown in Figure 1. Finer positioning is done by first moving the two outer BPM's to the point where they detect the beam, thereby pin-pointing the beam's trajectory. Then the center BPM is moved across the trajectory to measure the resolution of the beam. The three BPM assemblies are spaced 300mm apart and each assembly consists of a BPM that is supported by what is essentially a stewart platform as shown below in Figure 2. The platform is supported by six-struts. Each strut's axial length can each be adjusted through the use of a stepper motor mounted to each strut.. A side view of the strut is shown in Figure 3. The coordinated axial adjustment of the struts can move the BPM +/-200 microns in the XY-plane with a resolution of 0.1 microns. Similarly, coordinated adjustment of the struts can cause the BPM to rotate +/- 2000 micro radians about the X and Y-axes with a resolution of 10 micro radians. The strut's axial movement is powered by a stepper motor that opens and closes the two arms of the strut. These arms are held together with springs as shown in Figure 4. The axial displacement of the strut is +/-250 microns with a resolution of 0.02 microns. This fine resolution is achieved through a combination of the stepper motor's resolution and the mechanical leverage of the strut's levers.

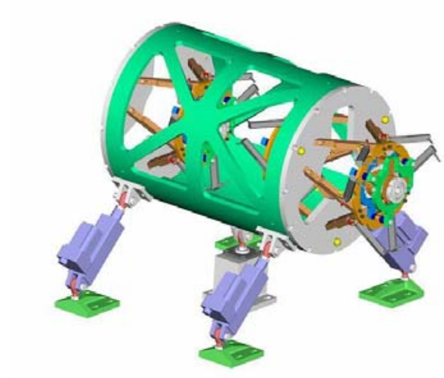

Figure 1: BPM alignment frame

Also shown in Figure 3 and 4 are the flexure pairs at either end of the strut. These act as "ball joints" to the strut and only allow an axial displacement to be transmitted to the platform. This basic strut design was successfully used as part of an extreme ultraviolet photolithography camera (2).

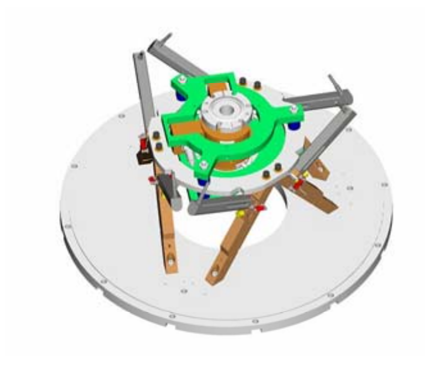

Figure 2: Pro/Engineer model of the BPM assembly.

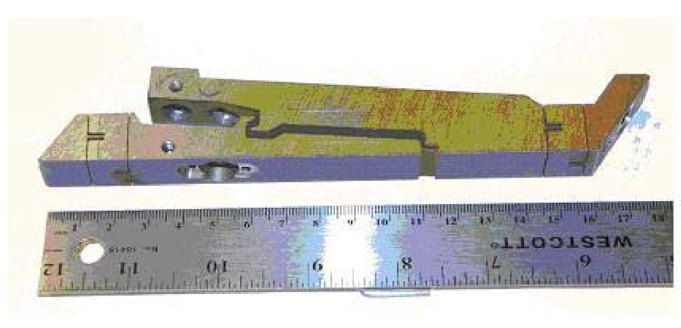

Figure 3: Side view of BPM strut without the linear motor, LVDT and springs.

Operation and Testing Alignment Frame

The ability to resolve the beam with the BPM's will be tested by moving the outer two BPM's such that they each capture and center the beam. The beam between the two BPM's forms a straight line whose expected position on the middle BPM can be calculated. The spread of BPM output readings from the expected position to the actual position of the center BPM will be used to determine the BPM's resolution. In order to get accurate measurements by the BPM's, the relative motion between the BPM's must be held to a minimum. The main source of excitation to the alignment frame is ground motion due to the environment. In order to reduce the impact on the BPM's motion it was import to have a sufficiently high 1st mode of vibration.

Testing of the frame included modal analysis and positioning performance of the BPM's. The first and second modes of vibration were found experimentally to be at 194 and 221 Hz with a mode shape of the BPM's moving in and out along the axial length of the tube. These results compared within 5% of the predicted modal response as simulated in ProMechanica using a simplified model of the complete assembly.

The relative motion of the BPM's was measured by using the ground motion to excite accelerometers attached to the 3 BPM's. The acceleration data was filtered and double integrated to calculate the displacement of the BPM's. This data on the outer BPM's was then used to calculate a straight-line trajectory and thereby the expected position of the center BPM. The actual position was compared with the expected position and was found to deviate at worst, 3.49 nm over 119 milliseconds of measurement. Whether this is too much relative motion will depend on the duration of the data acquisition during tests in the linear accelerator. Due to thermal and other effects this data acquisition window could vary from 10 to 100 milliseconds. Therefore if the window becomes larger than approximately 35 milliseconds, the relative motion of the BPM's could be too large to getting meaningful data for calculating the BPM's resolution.

Future Work

The future work will depend on the experimental results that are underway now in the KEK Linear Accelerator in Tsukuba, Japan. If the position performance of the device is precise enough and the relative motion of the BPM's is found to be small, the final phase of the project will be funded. This will involve the design and construction of a metrology frame. This frame will be made out of Carbon Fiber Reinforced Plastic (CFRP) and will serve as a reference when measuring the changes in position of each BPM. The frame will consist of a tube that fits over the alignment frame with extensions will support a small encoder or grid. A laser detector mounted on the BPM supporting ring will be used to measure diffracted signals bouncing off of the grid. CFRP was chosen because it is light, rigid and it is possible to design in a coefficient of thermal expansion (CTE) of zero in one particular direction. For this design, we have chosen the metrology tube's axial direction, in line with the beam, to have a zero CTE.

Conclusion

An Nano BPM alignment frame has been developed to support BPM's for nanometer level position measurements of the electron beam from a linear accelerator. Early tests agree with simulated results. However more complete tests are now underway to fully evaluate the performance of the alignment frame.

Reference

(1) Gronberg, J., "Colliding Nanometer Beams", Jan. 14, 2003, LLNL Proposal for new LDRD Exploratory Research.
(2) Hale, L.C., et al., "High-NA Camera for An EUVL Microstepper", 15th Annual Meeting of ASPE, Oct. 2000.

Figure 4: Side view during assembly showing the struts, the stepper motor and the LVDT.

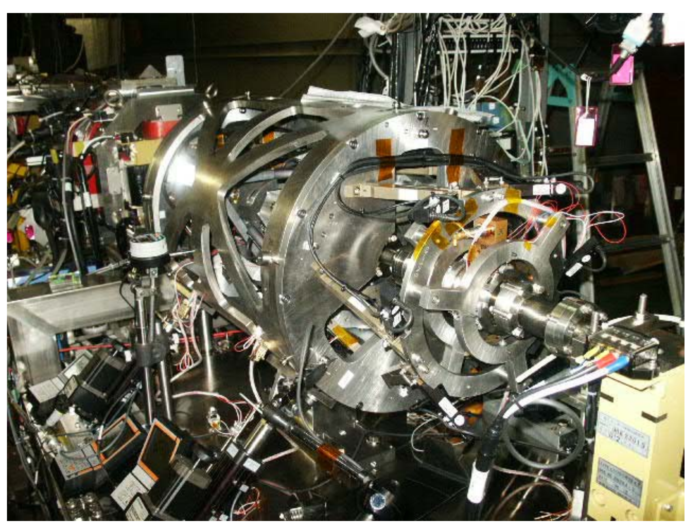

Figure 5: Fully assembled Nano BPM Alignment Frame installed in the KEK Linear Accelerator.

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